Definition of a bridge deck geometrical modelling process to automate design graphical representations

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Abstract
The construction of a new building interferes with the existent environment. A careful aesthetic study must be made at an early stage in the design and the visualization of a three-dimensional (3D) model of the structure is the best way to analyse it. As some structures presents a complex shape is difficult to execute a 3D model as well as the specific drawings. Using traditional graphical systems, the execution of deck specific drawings is extremely time consuming and the 3D deck model gives an approximation only of the exterior shape of the deck. The modelling scheme proposed here allows the automation of the geometric design phases related to the deck bridge element using as a means of integration a geometric database representative of the real deck shape. This concept was implemented in a computer program. This application is an important support in the process design namely at the conceptual and graphical stages. The computer application provides an important tool to the bridge designer particularly at the conceptual stage, as it allows aesthetic and structural evaluation of the bridge at an early stage in the design. The geometric modelling process and graphical results of a case study are presented.

Key words: geometrical modelling, deck geometric database, automation and integration in bridge design, bridge graphical support systems.

1 Deck box girder configuration

At the conceptual design stage, the bridge designer establishes the shape of a half-span cross-section and the analytical laws corresponding to the longitudinal evolution of the deck depth and of the thickness of the slabs and webs along the whole longitudinal axis of the bridge. Simultaneously, the top surface of the deck has to match to the geometry of the layout of the road, where the bridge is to be inserted. So, the top surface of the deck must present the geometry established for horizontal alignment, vertical alignment, transversal slope and over-width. This information is initial data included in the preliminary design documentation given to the bridge designer.

It is, therefore, possible to conclude, that the deck shape is influenced by two longitudinal geometric components:

- The morphologic evolution of the deck depth and the thickness of the slabs and webs along its longitudinal axis;
- The geometry of the layout of the road where the bridge is inserted.

The resultant configuration is, in general, complex, as these components act simultaneously. In order to model the configuration presented by a bridge deck, its overall shape should be considered, as it is generated by an initial cross-section that sweeps along the deck. In that trajectory, the cross-section shape and its spatial orientation are modified due to the geometry defined by those longitudinal deck components.
Therefore, since the real deck shape is complex, the definition of the usual deck representations needed in a bridge design is extremely time-consuming. Consequently, this is highly detrimental to the aesthetic and structural evaluation of the bridge at an early stage in the design process.

2 Bridge deck graphical application

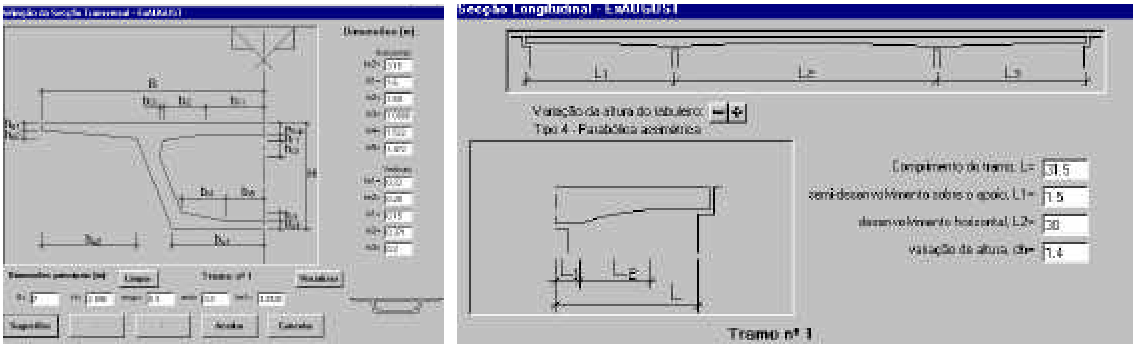
A computer application was developed within a PhD research program [1] [2]. It allows automatic execution while achieving the correct deck shape, of two specific drawings and a 3D-face model. It is based on a data set directly created by the bridge designer using the geometric data he deals with at the conceptual design stage. With this database, it is possible to generate a series of cross-sections involving only some or all the layout of the geometric information for the road. This methodology, based on the definition of cross-sections shape in several steps, allows the automatic generation of specific deck representations, needed throughout the bridge design process [3][4].
Three sequential modules compose this geometric application. Each one corresponds to a modelling step: the descriptive module, the cross-section generation module and the drawing module and the 3D modelling module.

2.1 Descriptive module

For a concrete bridge deck, the bridge designer directly creates the database, using the descriptive module. The descriptive data gives information about:

- The shape of a significant deck cross-section (a half-span cross-section);
- The evolution of the deck depth and the thickness of the webs and slabs along the deck;
- The layout of the road geometry (the horizontal and vertical alignments, the transversal slope and the over-width).

The deck cross-section configuration is described using the parametric shape presented in Figure 1 *a*. The sketch has sufficient parameters to allow the description of several cases concerning box girders. These parameters correspond to dimensions normally used in this type of drawings. So, the description of a cross-section is a natural task. The bridge designer also establishes the deck depth variation and the slab and web thickness variation of the new bridge deck. To describe this longitudinal component of the deck, several parametric sketches are defined. Figure 1 *b* shows the generic shape defined for the parabolic variation in the deck depth mode.
The parameters associated with the generic shape characterize, in a direct and complete way, this type of longitudinal variation, so they are sufficient to define as analytical expressions the trajectory for each cross-section vertex when the initial cross-section sweeps along a bridge deck segment. For the slab and web thickness variation (constant and liner increment) parametric shapes were established [2].



a *b*

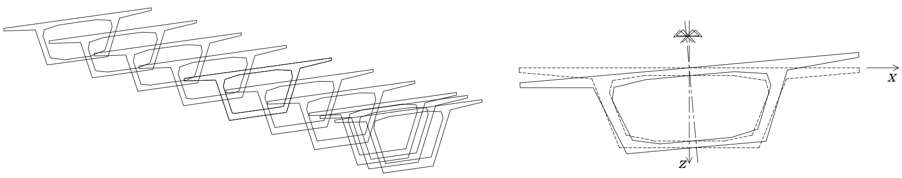
Figure 1: Parametric shape established for box girder cross-section and parabolic variation description.

Finally, the geometry established for the layout of the road is described. To characterize the components of the layout of the road (horizontal and vertical alignments, transversal slope and over-width), the geometric parameters and data normally used by the bridge designer are used. Thus, using the descriptive module, the database of any deck box girder can be created. The database defines the deck shape completely and exactly. Next, the cross-sections along the deck are generated, correct both in shape and spatial orientation.

2.2 Cross-section generation module

A bridge deck can be seen as a solid defined by a cross-section sweeping along the deck's longitudinal axis. The shape and spatial orientation of the initial cross-section (described using the descriptive module) are modified when it moves along the deck. The evolution of the deck morphology and the layout of the road geometry influence those modifications. Two steps compose the cross-section generation procedure:

- First, a series of cross-sections is defined along the deck as if it were straight and horizontal (Figure 2 *a*). Their shapes are determined due only to the variation modes established by the bridge designer for deck depth and slab and web thickness along the deck;



a *b*

Figure 2: Series of cross-sections generated along a straight and horizontal deck.

- Next, each generated cross-section is adapted to the layout of the road geometry. The vertex array of a cross-section is submitted to successive geometric transformations. First, the cross-section is adapted to the over-width (if applicable), afterwards, to the transversal slope (Figure 2 *b*).
- Then, the cross-section is positioned and oriented spatially using the geometric data of the horizontal (M, P and *azimuth*, Figure 3) and vertical (*elevation*) alignments calculated at the kilometric point (KP), a value that identifies the location of the cross-section into the road.

The deck representation module directly uses the 2D co-ordinate data of these cross-sections to execute the drawing of a series of cross-sections. These cross-sections must include the geometric information of the over-width and the transversal slope. To create the longitudinal section drawing, only the vertical alignment geometry must be added to each cross-section (defined on its own plane). The 3D co-ordinate data file of each cross-section is used to create 3D models.

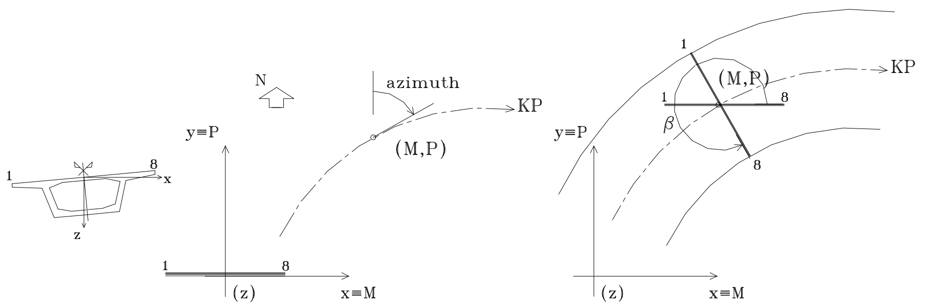
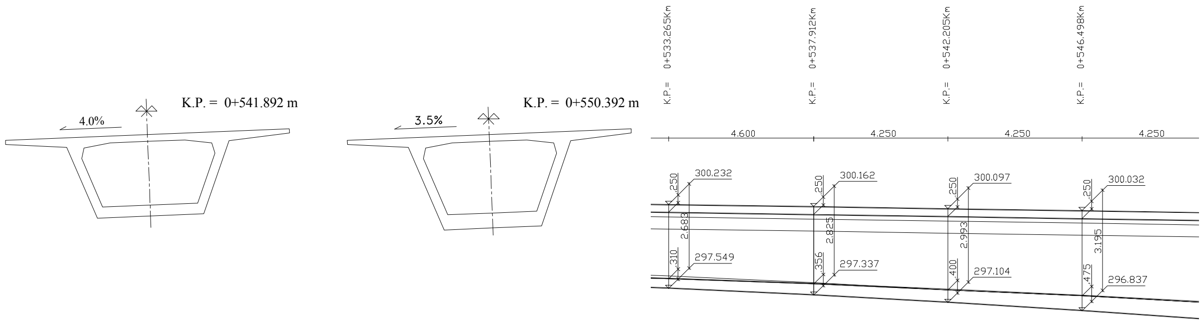


Figure 3: Cross-section adapted to the horizontal alignment geometry.

2.3 Drawing module

The computer program, that is described here, includes another module that allows the automatic creation of deck drawings and 3D models of great interest in a bridge design: cross-sections drawing, longitudinal section drawing of the deck and a 3D-face model of the deck.
Such deck representations are generated as drawing DXF files [5]. The algorithms to generate the distinct deck representations were based on the selection of a series of graphical entities that compose each type of representation. The DXF structure of a graphical entity is constant. Only the numeric values that particularize an entity are distinct, so the drawing module includes a routine procedure for each entity type used in any deck representation. The geometric parameters of each entity are variables. The routine procedure fixes with the values that identify each representation and lists the entity, on DXF format, in the drawing file.
The drawing of a series of sequential cross-sections, defined with their exact configurations, is a usual type of two-dimensional deck representation included in a bridge design's graphic documentation. At the conceptual design stage, this drawing is needed to evaluate the evolution of the cross-section shape along the deck axis.
A polygonal line is used to define each cross-section outline. The polygonal line vertices are fixed with the co-ordinate data included in the respective cross-section file. For this purpose all cross-sections must be defined as a 2D co-ordinate array. Therefore, the horizontal and vertical alignment geometry must not be incorporated in any cross-section, but the transversal slope data must affect all cross-sections to be represented (Figure 4 *a*). The cross-sections drawing DXF file is automatically complemented with the cross-section axis, the respective kilometric point (K.P.) data and the transversal slope value (Figure 4 *a*). Each represented cross-section is correctly defined in shape and located on the road.
The drawing of a deck longitudinal section is another type of two-dimensional representation usually required in the design graphical documentation. To define the drawing, one polygonal line for each longitudinal edge visualized on the deck longitudinal section is used. The number of vertices of each polygonal line corresponds to the number of consecutive cross-sections used to compose the longitudinal section of a deck segment (Figure 4 *b*).



a *b*

Figure 4: Representation of cross-sections and detail of a longitudinal section of a deck.

The longitudinal section representation includes data related to each cross-section: the kilometric point data, the elevation value over the deck longitudinal axis and the dimensions of the deck depth as well as the thickness of the top and bottom slabs. The respective values are automatically determined using the vertex co-ordinates and longitudinal location of each cross-section. At the conceptual design stage, the automation of this drawing is important, in order to be able to evaluate the evolution of the interior and exterior shape of the deck.

2.4 3D modelling module

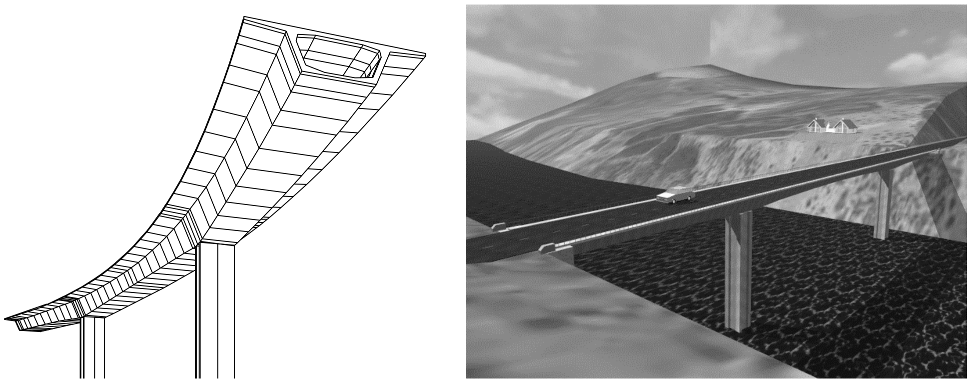
A 3D model of the deck is automatically generated using the system here described. Several solutions and redefinitions of the deck shape can be analysed at an early design stage. Thus, inaesthetic forms can be avoided by following the shape definition stage with a dynamic visualization.

The 3D deck model is composed of connected surface patches of four vertices. The model is formed by two tubular longitudinal surfaces: one representing the exterior shape of the deck and the other its interior. The top deck cross-sections are also defined showing surface elements. In this way the model projection looks solid.

This model represents the real configuration of the deck. In fact, on a curved deck, each constructive deck segment is defined with straight longitudinal lines. As this model uses cross-sections correctly defined in shape and in their spatial orientation, we can say that, it represents the real form of the deck, both exterior and interior. It is clear, therefore, that where traditional models cannot provide the means to visualize the interior, this model does.

The principal interest of this geometric model is, naturally, to allow a highly realistic visualization of the complete bridge. Using all the cross-sections generated along it is possible to create a 3D deck model. Moreover, it can be complemented, using a traditional solid modelling system, with other structural elements and bridge details defined as surface or solid models (Figure 5 *a*).

The 3D bridge model allows this visualization of the structure from any point of view. It is possible to apply algorithms to simulate colour, material patterns and the incidence of different type of lights to the bridge model. The bridge model, presenting a realistic image, is of great interest at the conceptual design phase and at presentation sessions of the new bridge. In addition, the 3D bridge model can be inserted in its environment, also defined as a virtual model (Figure 5 *b*).



a *b*

Figure 5: 3D bridge model in orthogonal projection and inserted in a virtual environment.

3 Conclusions

The described graphical system allows the automation of geometric phases, related to the deck element, in the bridge design process. The computer program uses a geometric database representative of the real deck shape. The principal advantages of using the developed bridge deck application are:

- A considerable reduction in the time inherently needed in the elaboration of the graphical documentation of the deck usually included in a bridge design;
- The possibility to actualise the deck geometric database easily as frequently required at the conceptual design phase. As any modification of the initial shape is rapidly visualized (in the form of drawings and 3D models) it conduces to optimise deck shapes;
- The definition of 3D deck models formed with cross-sections correctly defined in shape, orientation and position. The model thus represents the exact deck configuration and, in addition, its interior visualization is allowed. This model has the advantage over traditional approximation modes f defining 3D deck models.

4 References

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